Investigation of Model Sensitivities and Model Errors
With Relation to Data Assimilation Systems

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LONG-TERM GOALS

To investigate basic predictability issues related to model sensitivities to uncertainties in the initial and boundary conditions; how these sensitivities are dependent on different model dynamics and different data-types; how their assessment can lead to the evaluation of model errors as intrinsic component of the data assimilation system used.

OBJECTIVES

a) To assess the dynamical mechanisms that ultimately limit the predictability of a flow system.
b) To assess how the flow predictability is dependent upon uncertainties in the initial and/or boundary conditions.
c) To assess uncertainty in models by evaluating estimates of model error covariances from the assimilation method used.

APPROACH

I. The first part of the work is a collaboration under the DRI between Dr. Malanotte-Rizzoli of MIT and Dr. Steven Meacham of AER. At MIT Dr. Jim Lu was Postdoctoral Associate for one year under P. Malanotte-Rizzoli ONR-DRI Grant N00014-98-1-0881, from 04/01/1999 to 03/21/2000. At AER, Dr. Amala Mahadevan is a Postdoctoral Associate under the ONR-DRI Grant of Dr. Steven Meacham.

This effort focuses on investigating the predictability of strongly nonlinear, jet-like currents which can be used as idealized models for the energetic western boundary current systems. The predictability is studied by evaluating the singular vectors and singular values of the system.

The singular values associated with optimally growing perturbations to stationary and time- dependent solutions for the general circulation in an ocean basin provide a measure of the rate at which solutions with nearby initial conditions begin to diverge, and hence of the predictability of the flow. In this application, the singular vectors and singular values of stationary and evolving examples of wind-driven, double-gyre circulations in different flow regimes axe explored. By changing the Reynolds number in simple quasigeostrophic models of the wind-driven circulation, steady, weakly aperiodic and chaotic states may be examined. The singular vectors of the steady state reveal some of the physical mechanisms responsible for optimally growing perturbations. In time-dependent cases, the dominant singular values show significant variability in time indicating strong variations in the

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14. ABSTRACT
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15. SUBJECT TERMS

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predictability of the flow. When the underlying flow is weakly aperiodic, the dominant singular values covary with integral measures of the large-scale flow such as the basin-integrated upper ocean kinetic energy and the transport in the western boundary current extension. Further, in a reduced gravity quasigeostrophic model of a weakly aperiodic, double-gyre flow, the behavior of the dominant singular values may be used to predict a change in the large scale flow, a feature not shared by an analogous two-layer model. When the circulation is in a strongly aperiodic state, the dominant singular values no longer vary coherently with integral measures of the flow. Instead, they fluctuate in a very aperiodic fashion on mesoscale time scales. The dominant singular vectors then depend strongly on the arrangement of mesoscale features in the flow and the evolved forms of the associated singular vectors have relatively short spatial scales. These results have several implications. In weakly aperiodic, periodic, and stationary regimes, the mesoscale energy content is usually relatively low and the predictability of the wind-driven circulation is determined by the large-scale structure of the flow. In the more realistic, strongly chaotic regime, in which energetic mesoscale eddies are produced by the meandering of the separated western boundary current extension, the predictability of the flow locally tends to be a stronger function of the local mesoscale eddy structure than of the larger scale structure of the circulation. This has broader implication for the effectiveness of different approaches to forecasting the ocean with models which sequentially assimilate new observations.

II. On July 1, 2000, Dr. Mark Buehner has become Postdoctoral Associate at MIT under P. Malanotte-Rizzoli's DRI Grant. The following work is a contribution from MIT only.

An extended Kalman filter has been developed for the same reduced-gravity, quasi-geostrophic model used in part I. A reduced-rank assimilation scheme has been developed in which the error covariances associated with the state estimate are represented only in a reduced-dimension subspace. As a result, the corrections made to the forecast at each analysis time only span this subspace. We use the leading empirical orthogonal functions (EOF) calculated from a model run without assimilation as the basis function of the subspace, but the full model is used to produce the forecasts.

A series of assimilation runs were performed using a set of observations of the value of potential vorticity at 30 model grid-points distributed mostly near the western boundary (Figure 1). Observations are available about every 44 days.

The subspace was scanned by the first 50 leading EOFS. The dynamics were linearized with respect to the time-mean state and the model error covariances set to 5×10^{-5} (DB50-1) or 10^{-4} (DB50-2) times the climatological covariances.

For comparison purposes, the model was also integrated from the initial guess state without assimilation (the NULL run). A simple full-rank assimilation method was also run where the forecast error covariances are specified to have uniform variance and Gaussian correlations with the length scale of 5 grid spacings (the 0I runs). This approach was used with the observation error covariances set to zero (0I5), and also set to half the forecast error (0I5-RO5) and five times the forecast error (0I5-R5). Also, a more computationally expensive filter was run that uses the flow-dependent error covariances. These covariances were propagated in the EOF subspace by the linear dynamics operator recalculated at each analysis time.
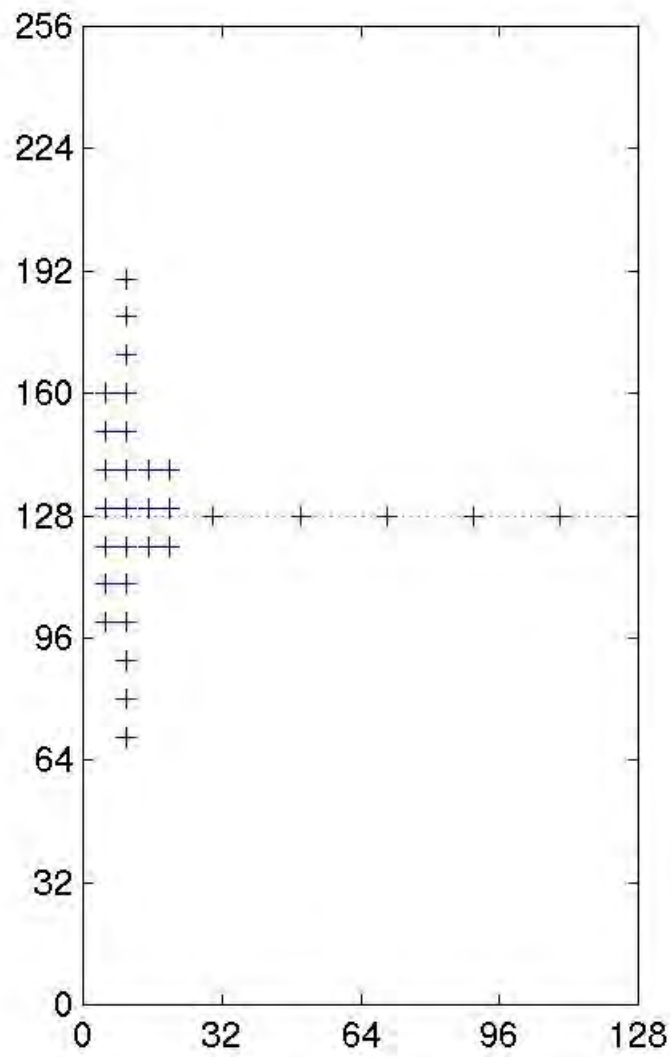
Figure 1: Locations of the 30 grid-points where potential vorticity is observed.
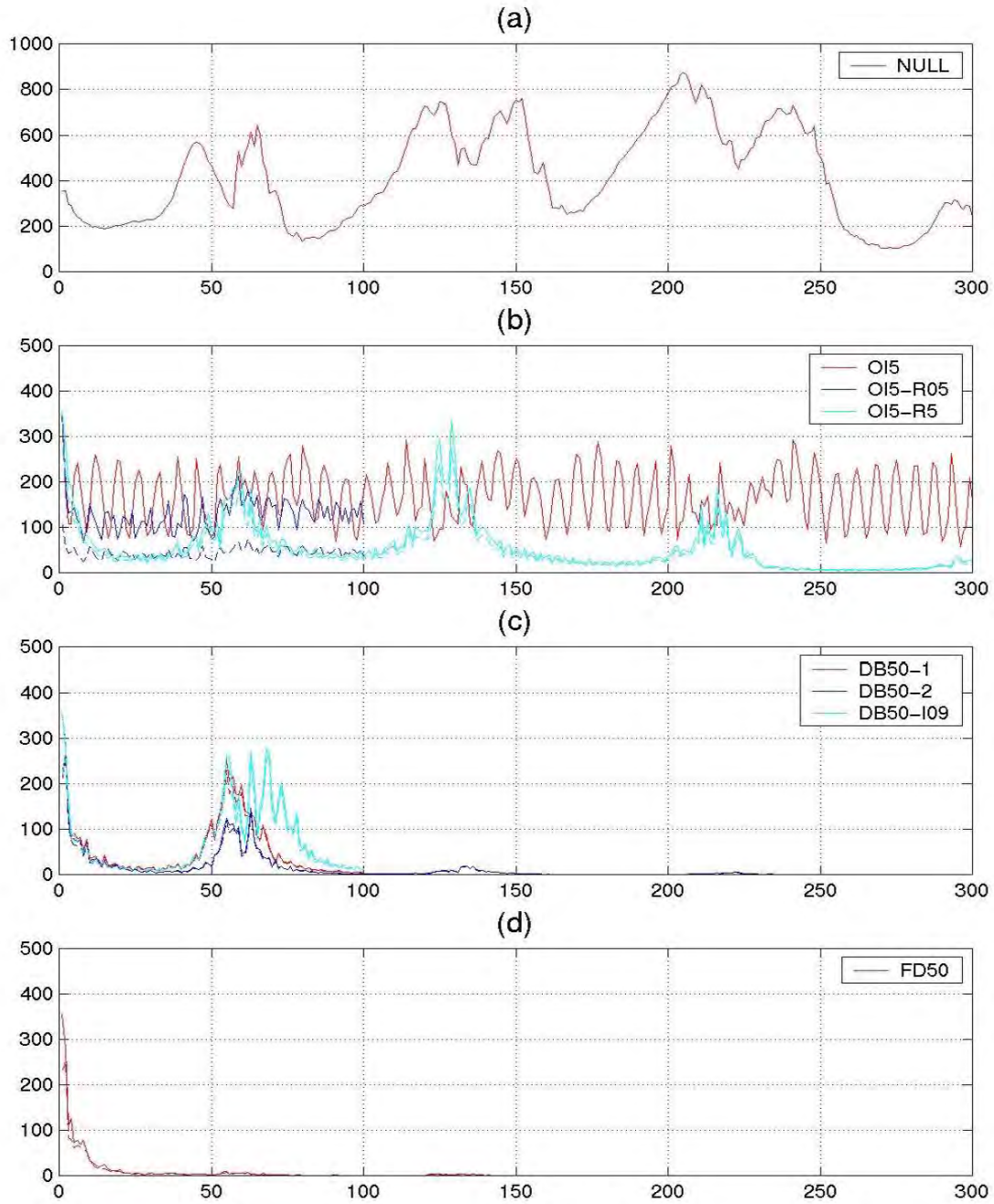
Figure 2: The root-mean-square error at the observation locations of the forecasts (solid curves) and analyses (dashed curves) for the following assimilation experiments: (a) no assimilation, (b) simple Gaussian forecast error covariances, (c) doubling algorithm with 50 EOFs, and (d) flow-dependent error covariances within the EOF subspace.

The RMS error of the forecasts and analyses evaluated at the observation locations are shown in Figure 2. The horizontal axis is the analysis time (i.e. 44 day increments). All of the filters were able to reduce the initial error rapidly. However, most suffer from increased forecast error during the periods of increased mesoscale activity. The stationary filter employing the higher model error estimate (DB50-2) performs better than any of the 0I runs.

PRESENTATIONS

EGS XXV General Assembly, Nice, France, April 2000, Malanotte-Rizzoli, P., and Jiang, S., 2000: On the predictability of regional oceanic jet stream: the impact of model errors at the inflow boundary.

Mahadevan, A., Lu, J., Meacham,, S.P., and Malanotte-Rizzoli, P., 2000: The predictability of large-scale wind-driven flows, submitted to the special issue of <u>Nonlinear Processes in Geophysics</u>, L. Smith and Z. Toth, editors.

PUBLICATIONS

Buehner, M., and P. Malanotte-Rizzoli, A low-rank stationary Kalman filter applied to a QG reduced gravity model, MIT internal report, submitted to <u>J. Geophys. Res</u>; abstract submitted to AGU special session on the DRI, San Francisco, December 2000.

Mahadevan, A., Lu, J., Meacham, S.P., and Malanotte-Rizzoli, P., 2000: The predictability of large-scale wind-driven flows, submitted to the special issue of <u>Nonlinear Processes in Geophysics</u>, L. Smith and Z. Toth, editors.